Learning from Two Types of Class Projects in Interactive Physical Prototyping: Comparison between Technology-driven and Experience-driven Project Results

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Abstract

Background Teaching technical prototyping skills is a major challenge for design educators. As interactivity becomes increasingly important in interaction design, more interactive prototyping methods are becoming necessary in the design decision-making process. Interactive physical prototyping methods requiring technical knowledge are a burden for designers who have weak technological proficiency. This indicates that educators need to teach their students prototyping skills in an easy but effective manner.

Methods This study involved the design implementation of two types of projects, technology driven (TtoX) and experience driven (XtoT), in an interactive physical prototyping class with thirty students. The two projects were conducted consecutively for ten weeks using Arduino and Entry. In the TtoX project, students were provided with information about technical materials for input and output and were required to select more than one material to develop a story. In the XtoT project, students started by defining users and their needs. The results of the two projects were analyzed and interviews were conducted with eight students to investigate their experiences regarding the two projects.

Results Students working on the TtoX project produced fourteen working prototypes, while those working on the XtoT project produced twelve working prototypes. In the TtoX project, students learned about how various electronic materials work and the actions they perform. By connecting input and output materials, students learned about the interactions between them and then developed stories using these interactions. This experience of matching a technology to an action helped students understand the relationship between electronic materials and actions, which is essential knowledge for interactive physical prototyping. The TtoX project also provided the opportunity to learn about technology. In the TtoX project, students were required to select and purchase materials and finish a small but complete prototype. This process was helpful for their future prototyping efforts. The technical barriers students faced in the TtoX project encouraged them to negotiate the interaction, which also gave them the opportunity to explore other interactions that are technologically feasible. Interestingly, students who failed to implement their first idea tried to develop a more attractive story for their prototype. Simple interactions could present opportunities to develop creative user experiences (UX) to compensate for simple interactions.

Conclusions The TtoX project, a technology-driven project, was very helpful in developing students' interactive physical prototyping skills and interaction design abilities. The most important effect of the TtoX project was that it provided students with an understanding of the relationship between action and technology. They were able to utilize this understanding in consecutive XtoT projects and to focus more on rich interactions.

Keywords Design Education, Interactive Physical Prototyping, Technology, Class Project

Citation: Kim, H. (2020). Learning from Two Types of Class Projects in Interactive Physical Prototyping: Comparison between Technology-driven and Experience-driven Project Results . *Archives of Design Research, 33*(3), 75-87.

http://dx.doi.org/10.15187/adr.2020.08.33.3.75

Received : Apr. 16. 2020 ; **Reviewed :** May. 26. 2020 ; **Accepted :** Jul. 20. 2020
pISSN 1226-8046 **eISSN** 2288-2987

This work was done by 2020 Baekseok University Research Fund and supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF- 2016S1A5A 8020572).

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1. Introduction

Prototyping is one of the most important and challenging issues in design education. In design, the prototype is a representation of the design decision made in the process before the final product and service is developed (Buchenau & Suri, 2000). In interaction design, prototypes are mostly used to test new interactions (Kim & Nam, 2013). Prototypes present different levels of design - “looks like,” “behaves like,” and “works like.” Depending on the level the prototype is intended to represent, designers require different prototyping skills (Kuniavsky, 2010). Designers must have prototyping skills in order to communicate their designs with others, especially clients.

Different levels of prototyping skills have been taught in design education. “Looks like” prototypes - often called mock-ups – require students to have a knowledge of materials, models, and structure (Cross, 1982). Most industrial design classes provide this education by requiring students to model their design ideas in 3D objects. Recently, 3D printing technology has eased the burden of modeling by hand, such as molding plastic materials. “Behaves like” prototypes assume the form of a story as the result of service design and UX design. The most frequently used method in this “behaving” prototype is the design scenario method, through which stories are presented through movies or story boards. This prototype requires designers to have storytelling and visualization skills. “Works like” prototypes show how the design result actually interacts with people, showing how people can manipulate the design and how the design reacts to such manipulations.

The working prototype represents a method of interaction, which can be conceived of as a conversation in which two people listen, think, and speak to each other (Crawford, 2002; Moggridge, 2007). Prototypes of interaction methods use a variety of materials – paper, digital, and actual devices (Saffer, 2009). Paper is a good material for understanding how a screen interface interacts with a user (Buxton, 2007). A digital prototype uses electronic materials. Digital prototypes are the most challenging for students and teachers in that they require technical knowledge, especially electronics and mechanical skills, which are difficult both to learn and teach. Many tools have been invented and studied in design research to enable designers to engage in interactive physical prototyping such as MIDAS (Yim & Nam, 2006), Arduino (Banzi & Shiloh, 2014), LittleBits (Lee, 2013), Makeymakey (Choi & Jung, 2016), Phidgets (Greenberg & Fitchett, 2001), and Basic stamp (Buchenau & Suri, 2000).

Although these tools effectively release designers and students from acquiring extensive knowledge about electronic technologies, design students who have primarily studied art still hesitate to learn these tools, as they may have minimal knowledge about technology. Since students’ difficulties represent challenges for educators, the issue of interactive physical prototyping skills has been studied in design education research. Choi and Jung (2016) separate knowledge about users from that about technology and emphasize that both types of knowledge are equally important and educators need to avoid focusing more on knowledge about technology. Kim (2011) developed a prototyping tool using conductive tape to reduce the problems in constructing electronic circuits in prototyping. Further, Lee (2010) found that the creativity of prototyping is related to the creativity of interaction.

This study investigates how an interactive physical prototyping class activity can be organized to enhance students' learning. To identify effective class structures and contents, technology-driven and experience-driven projects were first designed for the class with the purpose of increasing students' interactive physical prototyping skills and interaction design abilities. The effects of these projects were then examined.

2. Method

2. 1. Subjects

The students who participated in this study have a weak science and engineering education. The design college that the students attended granted admission based on a specific drawing exam. Most students in this kind of design college had more experience with drawing rather than studying other subjects such as mathematics and science, which makes them reluctant to study interactive physical prototyping requiring technical knowledge. The subjects were thirty students attending <Interactive physical prototyping>, with seventeen and thirteen students in two classes. All of the students had taken the prerequisite class – <UX & interaction design 1>, in which they had learned and practiced user-centered design methods, and were taking <UX & interaction design 2>, in which they conducted three projects: service design, mobile design, and interactive media for five weeks each. <UX & interaction design 2> simultaneously proceeds with <Interactive physical prototyping> as presented in figure 1.

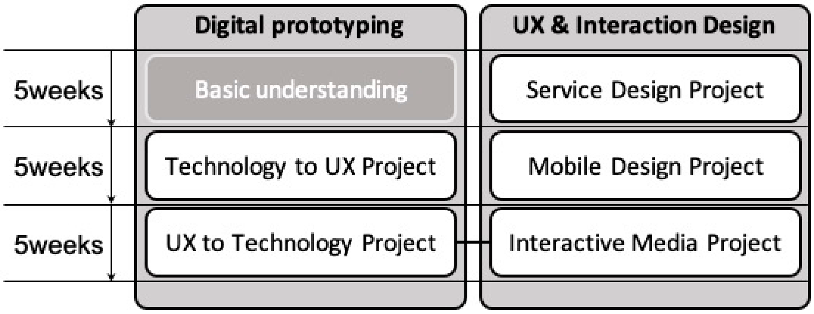

Figure 1 Class structure of 〈Interactive physical prototyping〉 and 〈UX & Interaction design〉

2. 2. Tool

To reduce the burden of studying technical issues in prototyping, this study uses Entry (2019), a block-based coding tool developed by KAIST (Korea Advanced Institute of Science and Technology), similar to Scratch, developed by MIT. The block-based coding tool uses a visual structure and logic, which allows everyone to easily access the code. In fact, Entry is mostly utilized in elementary schools. With its ease of use, the visualization of Entry helped the subjects of this study overcome their hesitance caused by their lack of technical understanding, as they are familiar with visual data and information.

2. 3. Design

Choi and Jung (2016) claim that the prototyping class should not only focus on the technology required for implementation of an interactive physical prototype but also on user experience. Balanced utilization of technical skills and a user-centered design method has been recommended by design educators. Nam (2006) designed an interaction design course with ten small exercises for practicing technical electronic skills and a final project integrating all knowledge acquired from the exercises. According to the students' feedback in this study, the number of exercises was too high, and some students faced difficulties in electronic circuit construction. Similarly, the author also observed that the longer the students learned the technical skills related to electronics and programming, the more they lost interest in learning in class and faced difficulty in prototyping.

Considering the problems determined in recent studies and the present author's teaching experiences, this study set two goals for the class projects: 1) gaining technical knowledge necessary for interactive physical prototyping; 2) developing the ability of utilizing technical skills in designing user experience; and 3) maintaining interest in learning through the course.

To achieve these goals, the first five weeks were spent understanding electronic materials such as breadboards, LEDs, resistors, and sensors; Entry as a software tool; and Arduino as a hardware platform with exercises.

The TtoX project, conducted by students between the sixth and tenth weeks, integrated small exercises for training each part of the electronic materials. This enhanced the students' technical knowledge acquired from the first five weeks and reduced the number of small exercises.

In the TtoX project, students were first provided with forty-eight electronic materials – sensors, actuators, and LEDs – that could be connected to Arduino and enable input or output interactions (figure 2). Students were required to choose more than one material from each given input and output material and create a story for the defined user and context. The TtoX project required students to embody interactions with input and output elements by solving technical issues and to explain the meaning of their design in terms of user experience. The TtoX project was conducted in teams of two students. Group work reduces the burden of the project and enhances learning effects through teamwork (Nam, 2006).

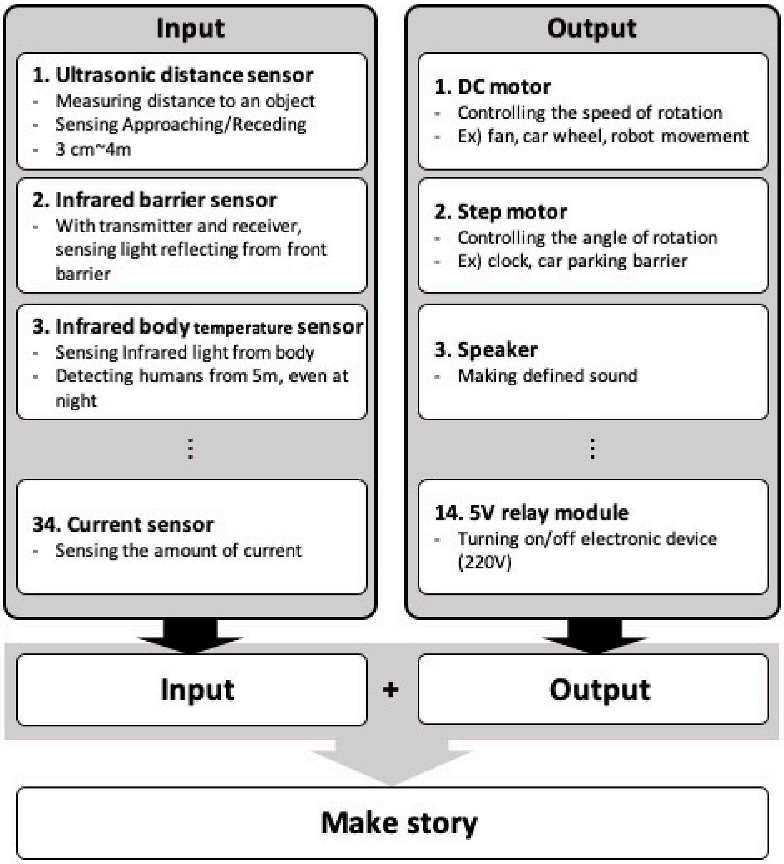

Figure 2 Given materials in the TtoX project

The XtoT project was designed alongside the interactive media project of the <UX & Interaction design 2> class (figure1). In the XtoT project, students were asked to design an "Interactive Game" and create a digital prototype to allow people to experience how the game works. The XtoT project was a team-based project.

In short, in the TtoX project, students engaged in UX design following technical prototyping with given materials, while in the XtoT project, they first designed a UX concept and then prototyped it, as seen in Figure 3.

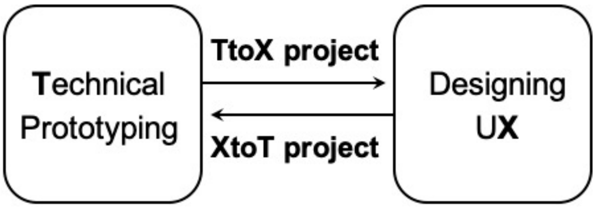

Figure 3 TtoX and XtoT projects

Both projects were designed for students to integrate their knowledge of technology and user experience.

2. 4. Interview

After the two projects, we conducted interviews with eight students who had taken the class.

Table 1 Interview Questions

	Questions
TtoX Project	What was your team's concept for the TtoX project? Describe the process that led you to the concept.
	What technical problems did you encounter in the TtoX project?
	What problems did you face in making the user's story in the TtoX project?
XtoT Project	What was your team's concept for the XtoT project? Describe the process that led you to the concept.
	What technical problems did you encounter in the XtoT project?
	What problems did you face in making the user's story in the XtoT project?
	Did the theme "interactive game" help you define your concept?
Relationship	Did the experience of the TtoX project help in the XtoT project? If it did, describe how the experience helped you with the XtoT project.

2. 5. Data collection and analysis

The TtoX project resulted in fourteen prototypes, while the XtoT project in twelve prototypes produced by thirty students. The documentations of all project outputs were collected and stored on an online server, and the simulations in project presentations were recorded on video. Some cases of prototype have been presented in this paper based on the interviewees' answers.

One-on-one interviews were conducted with eight students. The interviewees' answers were transcribed, followed by coding the data based on the grounded theory (Charmaz, 2006). First, each sentence in the data was open-coded. Thereafter, the extracted codes were clustered by meaning, such as action, technology, trouble, and negotiation. (Muller & Kogan, 2010).

3. Results

In the TtoX project, students produced fourteen working prototypes, while the XtoT project produced twelve working prototypes. After the two projects ended, interviews were conducted with eight students, called S01 to S8 in this paper. Students' answers to the interview questions (Table 1) produced the following findings.

3. 1. Matching Technology to Action

An analysis of the interview scripts showed that the relationship between electronic materials and actions plays an essential role in students' learning processes. Students often used it when describing difficulties they faced in the TtoX project as well as how the experience of the TtoX project helped them in the XtoT project. Students had no prior experience with coding or controlling basic electronic materials from breadboards to Arduinos and sensors. The TtoX project enabled students to understand how each electronic material works.

S01's TtoX project was called Finger Wresting. In the working prototype, a finger's push force bends a polystyrene stick, as shown in Figure 4. S01 described how they developed the concept as follows.

"Servo motors are rotative but can pull and push something when connected to the appropriate structure. This means that the pulling force can be controlled with the parameter of the Servo." – S01

Thus, S01 matched "servo motor" with the action of "pulling."

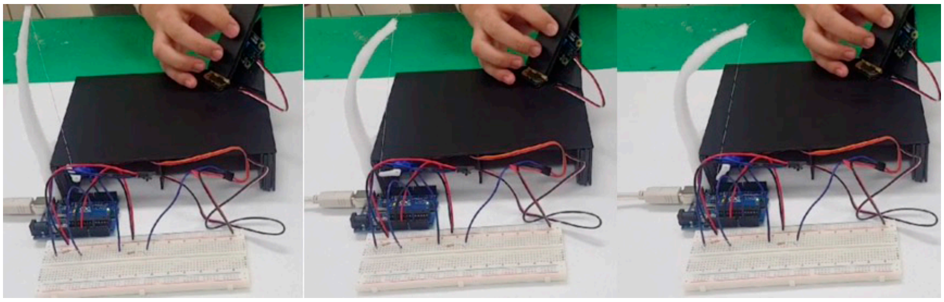

Figure 4 Finger Wresting – S01 concept in the TtoX project

S02 stated that he wanted to try as many sensors as possible, so his concept, "Sensitive Tanto," uses four kinds of sensors – touch, vibration, sound, and tilt sensors – in an elephant doll, as shown in Figure 5. The doll reacts to the user's action - talking, dropping, stroking its head, and shaking hands. In the interview, S02 stated that the TtoX project helped him learn how those sensors worked and he had no critical trouble in the next project.

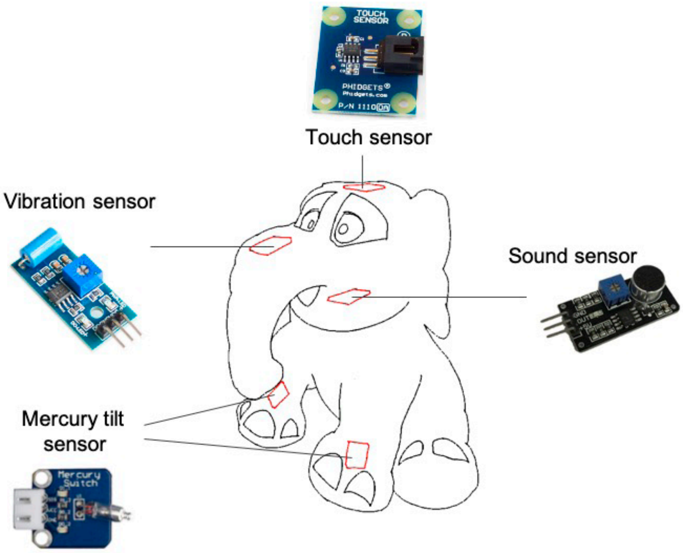

Figure 5 Sensitive Tantor – S02's concept in the TtoX project

Four students - S01, S02, S04, and S07– answered that they derived the user experience from the action in the XtoT project. They stated that they first came up with fun and creative interactions for interactive games. They made user experience stories using these interactions, then they iteratively modified the action and experience alternately.

In other words, the TtoX project gave the students the chance to learn what actions could be produced by technical materials. Understanding the relationship between technology and action helped the students match appropriate materials to a certain action, which is very important in designing the interaction and experience.

3. 2. Adapting to Technology

Compared to the XtoT project, the students faced many technical difficulties in the TtoX project. The students first had to select and purchase electronic materials to implement a working prototype with them. S03 described how he was shocked that the LED modules he purchased could not be connected to his Arduino because of a lack of digital pins. S04 mentioned the trouble she faced regarding the voltage of a string LED, which required an additional power supply. S01 recalled an embarrassing moment in which he found that the force of the servo motor was weaker than he had expected. S05 needed to abandon the heartbeat sensor she had purchased, which was neither sensitive nor accurate, to sense whether the user is walking or running. Interviewees also cited troubles they faced in determining purchasing appropriate materials online due to a lack of information and too many similar sensors and actuators.

"I never used breadboards and wires to make something before. The TtoX project made me become familiar with (+) and (-)."-S06

Like S06's statement, many students learned how to solve the problems they faced in coding or controlling sensors and actuators. At first, most students connected the materials together, but then found that there is no way to know where an error occurs. Students then started to verify each step by checking each connection with an LED.

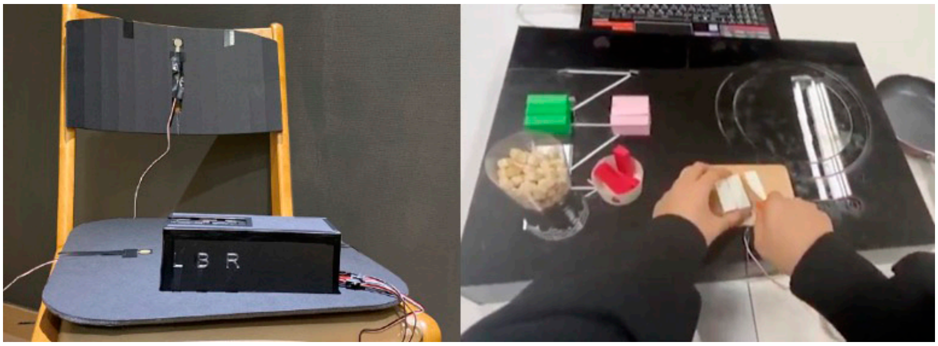

Figure 6 Pressure sensors used in the TtoX and XtoT projects by S07

S07 used pressure sensors to recognize bad posture while sitting on a chair in the TtoX project (left of figure 6). In the next project, she developed a set of cooking toys and used pressure sensors to determine what is being cooked (right of figure 6). She stated that the experience of using a pressure sensor in the TtoX project helped her develop the cooking toy.

"For the first five weeks, practicing exercise tasks with the professor gave us a basic knowledge of materials and coding. I thought I understood many of them at that time. However, in the first TtoX project, I did not know how to do anything. The first experience of coding in Entry and connecting sensors and LEDs was very helpful." – S05

As S05 mentioned, the TtoX project was helpful in that it gave her the opportunity to become familiar with electronic materials and coding processes to embody the knowledge required for prototyping.

3. 3. Negotiating with Technology

S06 described the process of developing her concept in the XtoT project as follows.
“When an idea for interaction was derived, we thought about whether we could implement it with Arduino. We tried to find fun and implementable interactions and made stories combining the interactions.” – S06

S08 illustrates the embarrassing moment of realizing he would have to develop a much simpler interaction compared to his original idea.
“We targeted kids for our interactive game. Changing sensors in the prototyping process resulted in a simpler interaction than our original idea. We believed that kids would not like the result, so we produced more ideas for richer interactions.”-S08
As seen in S08’s case, technical barriers made students negotiate the interaction and create more ideas to make richer interactions. Since the XtoT project was more focused on the user experience factor than the TtoX project, students struggled to design rich and creative interaction for target users. The technical difficulties they faced made the students iteratively modify the experience, interaction, and technology.

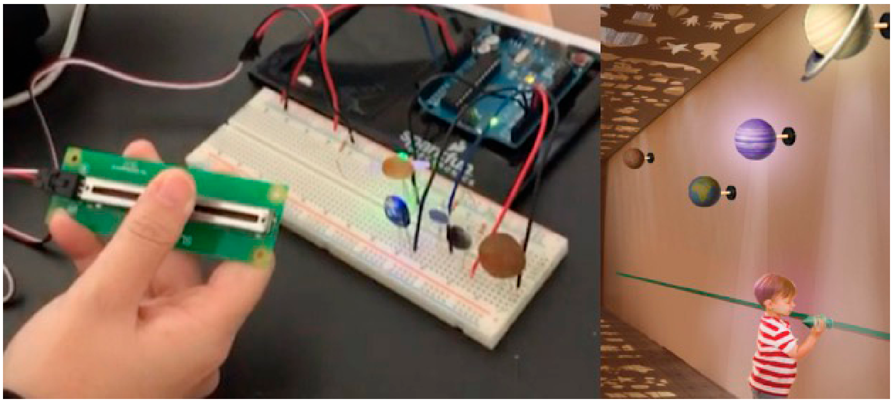

Figure 7 Simple interaction can dress user experience.

3. 4. Technology determines user experience

In the TtoX project, many students failed to implement their first idea. S05 needed to give up on her attempts to use a heartbeat sensor, which her team had curiously explored. As a result of wasting time with the heartbeat sensor, her team developed a simple interaction. In their final prototype, a slider brightens five LEDs linearly, presenting a story for children who want to be space explorers. Each LED represents a planet in the solar system and sliding indicates exploring from the sun to Mars (figure 7).

S04 had a similar experience. She also failed to combine two heartbeat sensors to recognize a couple’s level of affection for each other. After giving up using both sensors, she only had an LED that blinks in response to a heartbeat. Having read an article about how the hearts of old and unhealthy dogs are often irregular, she and her team finally developed a “pet health checking device” by enabling the sensor to be attached to the thigh of a dog’s hind leg with a Velcro string and visualizing the pet’s heartbeat.

These cases indicate that the purpose of the project in the prototyping class is not only to develop technical skills for using electronic materials and coding but also creating user experiences with limited access to technologies.

4. Implications for design education

This study has implications for design educators who are struggling to balance technical skills related to prototyping and design thinking based on user experience in their classes. Technology-driven projects enable students to link electronic and technical elements with action related to user experience. Technology-driven projects are started from given electronic materials not from a design concept or a target user group. Students must determine what kinds of actions to make with the given materials, which is the main goal of technology-driven projects. This demonstrates the process of technology-related thinking on actions and the user experience of the actions. During the project, the role of educators is to help students understand all course material, and not to develop design concepts.

One the other hand, experience-driven projects are commonly utilized. The target user group or concept keyword— “interactive game” in this study—is the starting point. In such a project, if no guidelines for using technical materials are provided, some teams are unable to produce physical interactions with the electronic materials. Therefore, the role of an educator is to guide the concepts of physical interaction in experience-driven projects.

5. Conclusion

In this study, two projects – TtoX and XtoT projects – were implemented in an interactive physical prototyping class. The TtoX and XtoT projects were carried out over a period of five weeks each with thirty students in two classes. Eight students were then interviewed about their experience and achievements in both projects.

In the TtoX project, students were provided with technical materials such as sensors, actuators, and display modules. They then developed a complete working prototype along with a simple UX concept. The core goal of the TtoX project was to help students experience the process of developing a complete prototype of their own concept. Students were required to select and purchase appropriate materials, write code using their own commands, and solve technical problems. Through this experience, students learned about which actions are enabled by each material, which is necessary knowledge for interactive physical prototyping.

Understanding the relationship between action and technology, as shown in Figure 7, enables students to focus more on rich UX concepts and implement diverse interactions. The XtoT project utilized students' understanding of the relationship between action and technology that they gained in the TtoX project. In the XtoT project, students were able to implement more complicated interactions and UX concepts than in the TtoX project. The consecutive manner in which the projects were implemented provided students with knowledge about technology-action, action-action, and action-user experience sequentially.

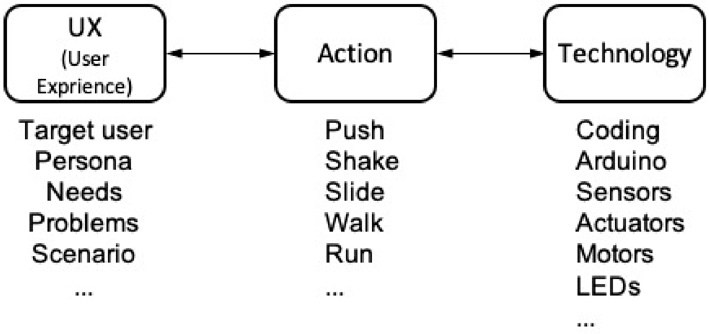

Figure 8 Learning Elements of Prototyping Class

Most interviewees agreed that their experiences with the two projects helped them gain interactive physical prototyping skills and made them confident in their abilities for prototyping in the future.

Since this study only suggests the direction of the two projects, it lacks details for educators who may want to implement similar assignments. Further studies are needed to establish specific guidelines, such as what information about technical materials in the TtoX project is most effective.

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